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FOREWORD

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This technical report has been reviewed and is approved.

Marshall K. Kingery
Research Division
Directorate of Plans
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ABSTRACT

The objective of this work was to measure the atomic line radiation of nitrogen in the spectral range from 7000 to 12,000 Å and to examine the population distribution of excited states to determine if a Boltzmann distribution existed and consequently whether an excitation temperature could be defined. Simultaneous measurements using Langmuir probes were made to determine electron temperatures. These measurements were applied to a low-density plasma produced in an arc-jet and expanded into a low-pressure chamber. A one-meter Czerny-Turner scanning spectrometer was used to record the atomic line spectra. Results indicate a difference in the spectroscopic temperature measurements and Langmuir probe measurements of approximately 2000°K. Reasons for this difference are discussed.

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SECTION I
INTRODUCTION

Measurement of the temperature associated with the various degrees of freedom of a gas molecule serves as a test of the degree of nonequilibrium. This work is concerned with atomic excitation temperature and free electron temperature in an arc-heated nitrogen plasma. The atomic excitation temperature is a parameter associated with a Maxwellian distribution of atoms in the upper excited atomic energy states. The free electron temperature is a parameter associated with a Maxwellian distribution of free electron velocity.

Since high-energy gases such as the arc-jet plasma are characterized by their radiant spectra, the use of spectroscopy as a measurement tool is possible. Many methods of measurement which utilize known theoretical expressions describing this radiation have been used. The method used in this report to determine atomic excitation temperature involves the relative intensity of emitted atomic lines. The logarithm of the measured intensity of each optically thin line lies on a straight line when plotted against the energy of excitation of the corresponding upper level. The excitation temperature varies inversely with the slope of this straight-line plot. The theory assumes a Maxwellian distribution of the population of the different electronic energy levels.

An independent electron temperature measurement was made using a conventional Langmuir probe immersed in the plasma stream. This method involves the Boltzmann relation for relative concentrations of electrons and depends on a Maxwellian distribution of electron velocity. Both the probe and the spectroscopic method are discussed in detail.

A common factor in both methods is the fact that the concept of a Maxwellian distribution of some energy parameter has entered each. It has generally been accepted that, in the type of electrical discharge considered here, the excitation process is dominated by electron-atom collisions. Therefore, the atomic excitation and free electron temperature would be expected to be the same. In experiments with an argon arc-jet, McGregor and Brewer (Ref. 1) found very good agreement between the two temperatures. The question then arises as to whether a plasma produced from a diatomic gas such as nitrogen exhibits a character similar to that of a plasma produced from a monatomic gas such as argon.

Results of the experiments reported herein indicate that there is no agreement between the measured atomic excitation and free electron temperature in a nitrogen plasma. An explanation of the results is

presented based on the assumption of some excitation process which is not electron-atom collision dominated and possibly non-Maxwellian.

SECTION II
APPARATUS, CALIBRATION, AND PROCEDURE

2.1 TEST CELL

The test cell was constructed from a steel cylinder 12 in. in diameter and about 4 ft in length. The cylinder was suspended vertically as shown in Fig. 1 (Appendix I). Spectroscopic measurements were made through two 5-in. -diam quartz windows. A plexiglass port contained a pressure relief valve and a vacuum-tight slip joint for probe instrumentation. The upper portion of the cell was surrounded by a water jacket to prevent heating of the cell walls during a run. The cell was evacuated by parallel 25- and 40-hp mechanical pumps. A pressure of approximately 0.3 torr could be maintained with a gas flow of 0.175 gm/sec.

2.2 PLASMA JET

The plasma was generated by a direct current arc-jet of the type shown in Fig. 2. It consists of a cylindrical rod tungsten cathode and a 0.25-in. -ID annular copper anode. Both the anode and cathode were water cooled. The gas enters the rear of the arc chamber, which is maintained at a pressure of 0.5 to 1.0 atm, passes through the arc, and is then expanded into the low-pressure test cell. Instrumentation was provided for constant monitoring of gas flow rate, arc chamber pressure, arc voltage and current, and cooling water temperature. A typical arc current was 240 amp at a potential of 50 v. A radio-frequency voltage applied between the electrodes initiated the arc process. The plasma stream was from 2 to 3 in. in diameter, and the visible portion extended about 3 ft. A normal shock wave existed about 4 in. downstream of the arc. The plasma color was normally pink.

2.3 SPECTROMETER

The spectrometer used for this study was a Jarrell-Ash one-meter Czerny-Turner scanning spectrometer. With an 1180-grooves/mm grating, dispersion in the first order was 8.2 Å/mm. The scanning system consisted of a 12-speed electrical drive with manual overdrive, having speeds from 15 to 2500 Å/min. Dual unilateral entrance and exit

slits were adjustable simultaneously from 5 to 400 μ with 2-μ graduations. Slit height was adjustable from 1 to 20 mm.

The spectrometer was mounted on a movable table that could be positioned vertically by a hydraulic jack and horizontally by a manual screw drive. Screw adjustments in the table supports provided for leveling.

2.4 OPTICS AND DETECTOR

When attempting to make optical spectrometric temperature measurements in a plasma stream with temperature gradients, it is important to know the exact field of view of the spectrometer and associated optics. To calculate local emission coefficients from observed intensities, an integral inversion procedure is used. The method used for the inversion required a parallel light path. The optical arrangement used included an achromatic lens placed at a distance equal to its focal length from the entrance slit of the spectrometer. The lens was stopped such that it had an f-number equal to that of the spectrometer. This ensured the filling of the spectrograph optics. A second stop of the same diameter (~0.125 in.) was placed about 5 in. in front of the lens. Alignment of the system was accomplished by backlighting the spectrometer with an He-Ne laser. The detector was an Amperex 150 CVP photomultiplier tube mounted in the Spex Photomultiplier Cryostat 1630-II. The useful spectral range of the tube was from 0.3 to 1.1 μ. Gradual cooling was accomplished in the cryostat by flowing nitrogen gas, obtained by vaporizing liquid nitrogen, over the photomultiplier tube and its resistor network. The rate at which the gas was evolved, and consequently the rate of cooling, could be controlled by varying the voltage across a resistance heating element submerged in the nitrogen storage dewar. The entire cryostat was insulated by a thick layer of foamed plastic. An evacuated, fused quartz cell served as an insulated window in front of the photomultiplier. Condensation on the face of the cell was prevented by diverting a small part of the flow of dry nitrogen gas so that it purged the cavity between the evacuated cell and the spectrometer exit slit. The temperature was monitored by a thermistor installed in the cryostat.

The photomultiplier tube was maintained at a potential of 1100 v. The detected signal was amplified by a factor of 100 and was then recorded on a strip-chart recorder having a variable sensitivity from 5 mv to 10 v.

2.5 INTENSITY CALIBRATION

To make emission intensity measurements, it is necessary to calibrate the spectrometer and optics with sources of known intensity. A relative intensity calibration was accomplished by using a calibrated tungsten iodide lamp. A plot of lamp radiance as a function of wavelength was made from the lamp calibration data. The lamp was placed at the position of the stream centerline and maintained at the specified current. Its radiant output was then scanned by the spectrometer over the wavelength range of interest. Chart deflections from this scan were then compared with the spectrometer trace of the plasma, and a calibration factor for each wavelength was calculated.

An absolute calibration was obtained by using a Model 11-200 Barnes blackbody having a 0.5-in.-diam aperature. The absolute radiance of the blackbody is given in tables (Ref. 2) as a function of the blackbody temperature and wavelength. For a known blackbody temperature, the absolute radiance can be determined as a function of wavelength. As in the relative calibration, the blackbody was scanned over the wavelength range used. The absolute intensity versus wavelength data from the blackbody is compared with that from the plasma scans to obtain the absolute emitted energy of the plasma at the various wavelengths. Since the observed intensity is directly proportional to the chart deflection, the energy of a particular line is given by

$$N_{plasma} = N_{blackbody} \times \frac{\text{deflection due to plasma}}{\text{deflection due to blackbody}}$$

$$N_{blackbody} = \bar{N}_{blackbody} \times \Delta\lambda$$

$\Delta\lambda$ = bandpass of the spectrometer

$\bar{N}_{blackbody}$ = average energy across the width of the bandpass

2.6 LANGMUIR PROBE

The Langmuir probe is illustrated in Fig. 3a. A platinum wire was inserted into a 0.0625-in.-ID ceramic tube. The wire was melted to fill one end of the tube, and the platinum surface was made planar with this end of the tube. This tube was mounted in a water-cooled copper jacket which extended through the plexiglass window by means of an O-ring slip joint so that the probe could be moved in and out of the plasma stream. Earlier experiments (Ref. 1) had shown that a noble metal must be used to prevent oxidation which caused changes in probe characteristics. Platinum probes were found to give consistent measurements. The probe circuit is shown in Fig. 3b. Data were recorded on an x-y plotter.

2.7 PROCEDURE

Approximately one hour before each run, spectrometer electronics were turned on to allow time for stabilization. The photomultiplier cooler was started and regulated until a constant temperature was obtained. The arc-jet power supply, gas, and cooling water were then turned on. The arc was struck by means of a radio-frequency pulse. The gas flow and power were adjusted to obtain the most stable operating conditions. This was usually obtained with a high power (10 kw) and a low flow (0.175 gm/sec). The arc-jet and test cell conditions were visually monitored frequently throughout the run to ensure steady-state operation. Each of six spectral lines in the spectral region from 0.7 to 1.1 μ was scanned at 0.25-in. intervals across the plasma stream at a position approximately 2 in. downstream of the normal shock. Scan speed was 50 Å/min.

Langmuir probe data were then taken at the same position in the stream, also at 0.25-in. intervals.

SECTION III
NITROGEN PLASMA

The composition of the nitrogen plasma emanating from the arc region of the arc-jet includes neutral molecules and atoms; molecular and atomic ions, and free electrons. The radiant energy emitted from the plasma arises from transitions of bound electrons from higher to lower atomic energy states and from transitions of free electrons to either bound states or to different free states producing radiation that is continuous with frequency.

The dominant radiation from the nitrogen plasma consisted of molecular bands of the N_2^+ first-negative system and the N_2 second-positive system. Many atomic lines also appeared in the spectral range from 7000 Å to 1.2 μ. No molecular bands were observed in the near infrared, and the continuum intensity was extremely low; therefore, atomic lines in the region from 0.7 to 1.1 μ were useful for temperature measurements.

The energy level diagram for the nitrogen atom is illustrated in Fig. 4. Each energy level shown is actually split into several closely lying levels because of spin-orbit coupling. Consequently, the transitions indicated by the solid lines between the respective upper and lower quantum states are actually associated with several transitions which

produce a group of spectral lines with closely spaced wavelengths. These groups of lines are called multiplets. It is possible to use the integrated total intensities of the multiplets for temperature calculations; however, the calculations in this report were made using individual lines. This was accomplished by using a spectrometer with sufficient resolution to resolve the individual lines in the multiplet.

Each transition involved is characterized by a transition probability (A_{nm}) defined as the probability of spontaneous transition by one atom in one second. Values of transition probabilities for the spectral lines used in the calculations were taken from a compilation by the National Bureau of Standards (Ref. 3) and are listed in Fig. 4. Uncertainties in these values are given as from 10 to 25 percent.

SECTION IV
TEMPERATURE MEASUREMENT THEORY

4.1 RADIAL INVERSION PROCEDURE

Since temperature gradients exist along the path of radiation as seen by the spectrometer, local emission coefficients must be calculated from the observed intensities by an integral inversion procedure (Ref. 4). In optically thin plasmas of radius (r_o), the intensity in terms of the emission coefficient $\epsilon(r)$ is

$$I(y) = 2\int_{o}^{(r_o^2 - y^2)^{1/2}} \epsilon(r)dx = 2\int_{y}^{r_o} \frac{\epsilon(r)\,r\,dr}{(r^2 - y^2)^{1/2}} \qquad (1)$$

if one assumes a cylindrical column which is observed in the x direction at a distance y from the zx plane as in Fig. 5a, and the emission depends only on the r coordinate. The Abel transform then gives the emission coefficient as

$$\epsilon(r) = -\frac{1}{\pi}\int_{r}^{r_o} \frac{\frac{d}{dy}[I(y)]\,dy}{(y^2 - r^2)^{1/2}} \qquad (2)$$

The emission coefficients may be found by a direct solution of the integral; however, since the derivative of I(y) is involved, small errors in I(y) may cause serious uncertainties in $\epsilon(r)$. An approximate method involves a solution of a finite set of linear algebraic equations,

$$I_j = \sum_i A_{ij}\,\epsilon_i \qquad (3)$$

where i refers to a radial zone and j to an increment along y. This summation is over the path of radiation, and each zone is weighted according to its area as shown in Fig. 5b. The weighting factors A_{ij} are given by Pearce (Ref. 5) for axisymmetric geometry.

A computer program was written to determine solutions of the linear equations. Computer plots of the intensities normalized to the maximum value and calculated emission coefficients for a typical run are shown in Figs. 6 through 17. The computer program provided for a fourth over a second-degree polynomial curve fit for the intensity data. The intensity data were extrapolated for positions of radial distance beyond 1 in. because of unreadable chart deflections in this region.

4.2 RELATIVE LINE INTENSITY METHOD

For an optically thin line in zone i the emission coefficient is

$$\epsilon_{inm} = \frac{1}{4\pi} h\nu_{nm} A_{nm} g_n \frac{N_i}{Q_i} \exp\left(-\frac{E_n}{kT_i}\right) \tag{4}$$

where it is assumed that there is only spontaneous emission, and the energy levels of the emitting species have been populated by a mechanism possessing a Maxwellian velocity distribution. Cross multiplying and taking logarithms yield

$$\ln \frac{\epsilon_{inm} 4\pi}{h\nu_{nm} A_{nm} g_n} = \ln \frac{N_i}{Q_i} - \frac{E_n}{kT_i} \tag{5}$$

where:

h = Planck's constant = 6.62517×10^{-34} joule-sec
k = Boltzmann's constant = (1/11,605.4) ev/°K
ν_{nm} = frequency of spectral line in sec^{-1}
A_{nm} = transition probability for transition from nth to mth level in sec^{-1}
g_n = statistical weight of nth state
N_i = particle density in ith zone in cm^{-3}
Q_i = partition function in ith zone = $\Sigma g_n \exp\left(-\frac{E_n}{kT_i}\right)$
E_n = energy of nth level in ev
T_i = temperature of ith zone in °K

The graph of

$$\ln \frac{\epsilon_{inm} 4\pi}{h\nu_{nm} A_{nm} g_n}$$

versus E_n for the different spectral lines is a straight-line plot whose slope is $(-1/kT_i)$. Thus

$$T_i(°K) = - \frac{1/k}{\text{slope}} \tag{6}$$

The temperature can be determined without knowledge of particle density; therefore, only relative intensities are needed to calculate the local emission coefficients.

The slope was found by a least-squares-fit computer program. Deviations from the straight-line plot were small. Typical results for the radial temperature distribution are shown in Fig. 18. The scatter of points at radial distances greater than 1 in. is attributed to the extrapolation of intensity data in this region.

Similar calculations were carried out using the intensity data (I_j) in Eq. (4) rather than the emission coefficients ($\epsilon(r)$) which were found by the radial inversion procedure. This method gives a weighted temperature over the path of radiation and is a true measurement only if the path is isothermal. The computer plot of radial temperature is shown in Fig. 19. A comparison with Fig. 18 indicates that the plasma was very nearly isothermal across the path of radiation.

4.3 ABSOLUTE LINE INTENSITY METHOD

To determine a temperature by direct substitution in Eq. (4), the particle density must be known. Since the degree of dissociation in the plasma is not known precisely, a calculation of particle density would only be approximate. However, by plotting absolute intensities in Eq. (5) for several different spectral lines, the value of

$$\ln \frac{N_i}{Q_i}$$

will be given by the intercept of the curve. Results of particle density measurements using this method are discussed in Section V.

4.4 LANGMUIR PROBE METHOD

Typical Langmuir probe data as shown in Fig. 20 are obtained by varying the probe potential relative to the plasma and recording the probe current. Boltzmann's relation (Ref. 6) can be used to determine

relative electron concentrations. The electron current density to the probe is

$$j_{es} = j_{ep} \exp\left(-\frac{eV_o}{kT_e}\right) \tag{7}$$

where j_{ep} is the random plasma electron current density, e is the electron charge, V_o is the probe potential relative to the plasma, k is the Boltzmann constant, and T_e is the absolute temperature of the plasma electrons. Taking the natural logarithm of each side gives

$$\ln j_{es} = \ln j_{ep} - \frac{eV_o}{kT_e} \tag{8}$$

The logarithm of electron current to the probe is a linear function of probe voltage as long as the voltage is retarding the electrons and the electrons have a Maxwellian velocity distribution. The temperature (T_e) may be determined from the slope (e/kT_e) of the straight line obtained when $\ln j_{es}$ is plotted versus the voltage. A typical plot is shown in Fig. 21.

SECTION V
RESULTS AND DISCUSSION

Results of the spectroscopic and probe temperature measurements for radial positions in the plasma stream from the centerline to 1 in. are listed in Table I (Appendix II) for a typical run. Similar values were found in each of several different runs. The electron temperature was always approximately 2000°K higher than the atomic excitation temperature.

A previous experiment (Ref. 1) using argon as the working gas yielded results as shown in Fig. 22. Here, the agreement between electron and excitation temperature was excellent. The temperature gradient across the stream, which was small, was similar to the results of the measurement in nitrogen.

In the case of argon, the excitation mechanism was postulated to be by collisions of electrons with metastable atoms. The metastable mechanism would also seem to be a possible one in the nitrogen plasma because of lifetime considerations. The approximate time for gas flow from the arc to the region of investigation was 10^{-3} sec. The mean lifetimes of excited atoms and molecules in the nitrogen plasma are on the order of from 10^{-6} to 10^{-8} sec. Temperatures of the gas and free

electrons in this region are insufficient to produce the observed atomic line radiation. For atoms or molecules in metastable states, there are no electric dipole transitions. The mean life, or time after which the number of atoms left in a particular quantum state is 1/e of the initial number, is on the order of 10^{-3} for magnetic dipole transitions. If electric quadruple transitions are possible, the mean life is on the order of one second. Therefore, metastable atoms should exist in the region of plasma under investigation.

In the argon plasma, the metastable states of argon lying at 11.5 and 11.7 ev as shown in Fig. 23 were postulated as the base for a new distribution function. The upper excited states of the argon atom lie at about 12 to 14 ev; therefore, only about 2 to 3 ev per collision were required for excitation. If this postulated mechanism in which electron impacts dominated the collisional rate processes was responsible for excitation, then agreement between electron and excitation temperature would be expected.

In nitrogen, the atomic metastable states lie at 2.4 and 3.6 ev. The next excited states of the atom are at 10.5 ev and higher. For excitation by the electron-metastable collision mechanism, 7- to 10-ev collisions would be required. Since the average electron energy is only about 0.5 ev, very few electrons would be capable of exciting the upper states. Thus an equilibrium between atomic excitation and free electrons based on this postulated mechanism would not be expected.

Other excitation mechanisms for the nitrogen atom have been suggested in which electron-atom collisions are not the dominant energy exchanges. The dissociative recombination of N_2^+ into an excited atom and a ground state atom (Ref. 7) has a fairly large cross section. This process,

$$e + N_2^+ \rightarrow N^* + N$$

would produce excited atoms with as much as 14 ev of energy.

Another nitrogen atomic metastable has been reported by Prag and Clark (Ref. 8). Atoms in the ^6S level which have an energy estimated by isoelectronic extrapolation to be 17.2 ev are assumed to participate in the formation of loosely bound N_4 molecules. These molecules can release sufficient energy to excite the upper states of the nitrogen atom through collisions involving single electron exchanges. This process has not been experimentally verified.

Excitation involving molecular metastables has also been suggested (Ref. 9). The molecular metastables of nitrogen lie in the energy

range from 6.2 to 8.9 ev and have half-lives up to one second. The process,

$$N_2^m + N^m \rightarrow N_2 (X' \Sigma_g^+) + N^*$$

where N_2^m is the molecular metastable and N^m is the atomic metastable, could produce sufficient energy (~12.5 ev) to populate ten or more excited states of the nitrogen atom. The small population of either metastable relative to the total particle population makes this process unlikely.

It is probable that the excitation mechanism involved does not produce a Maxwellian distribution of atoms in the upper states. Although good straight-line Boltzmann plots were obtained, the values for total atom density found by the absolute intensity method described in Section 4.3 were quite high. Densities on the order of 10^{17} atoms/cm^3 would be expected, considering the operating conditions of the jet. However, the experimental values were on the order of 10^{40} atoms/cm^3. Calculations of the atom density in a particular excited state yielded values on the order of 10^6 atoms/cm^3. These values were reasonable for the plasma conditions; therefore, the discrepancy in the total atom density could be attributed to the failure of the distribution function to describe the atomic excitation.

SECTION VI
CONCLUDING REMARKS

Evidence has been presented that the temperature determined by spectroscopic measurements in a nitrogen plasma does not agree with free electron temperature. The explanation is thought to be that the excitation of atoms to the upper atomic states is not electron-atom collision dominated. Other excitation mechanisms were postulated, and the probability of deviation from a Maxwellian distribution was suggested. It is quite possible that these results would apply to other diatomic gases with similar energy levels; however, no investigations with other gases have been conducted.

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APPENDIXES

I. ILLUSTRATIONS

II. TABLE

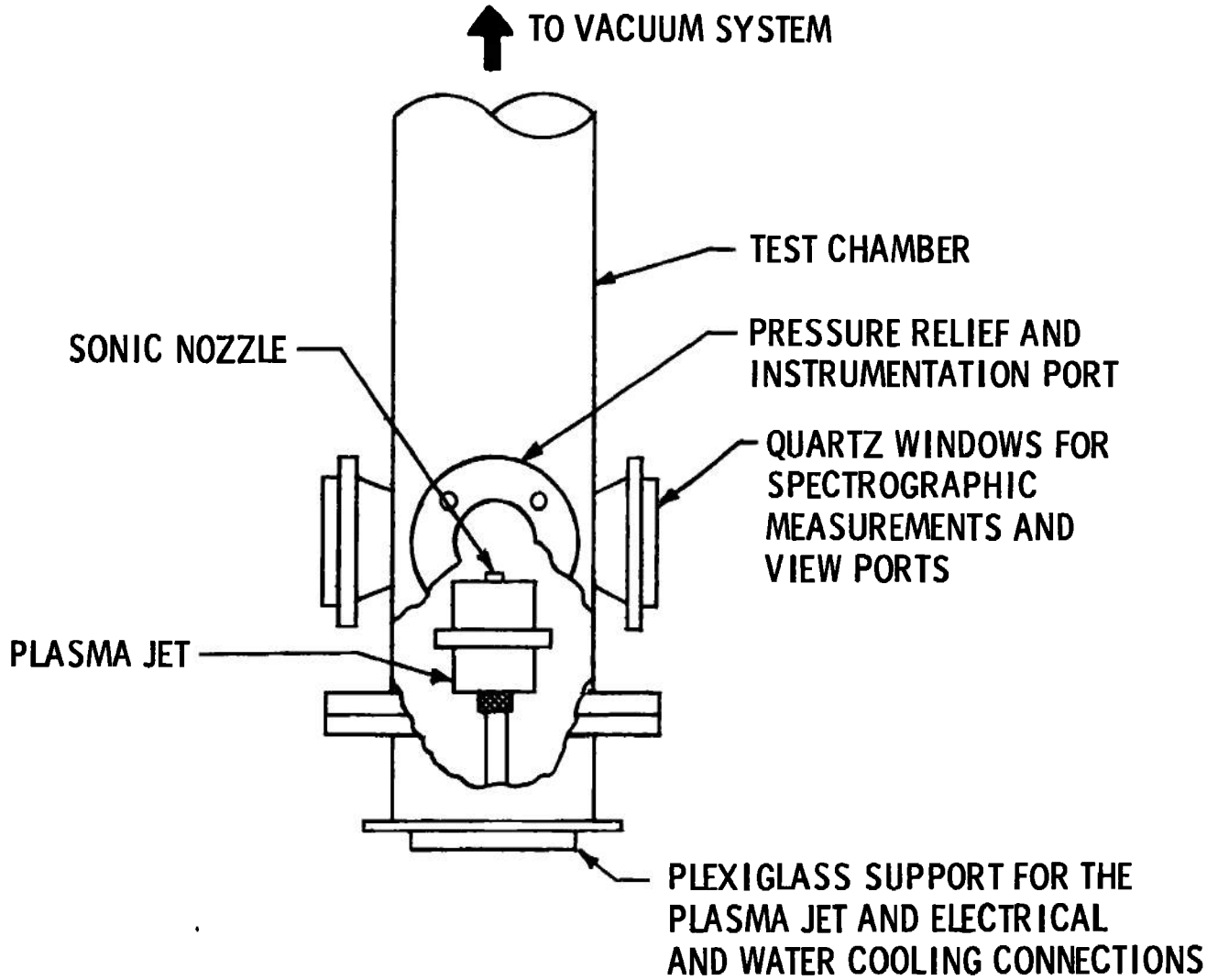


Fig. 1 Test Cell Schematic

AEDC-TR-68-187

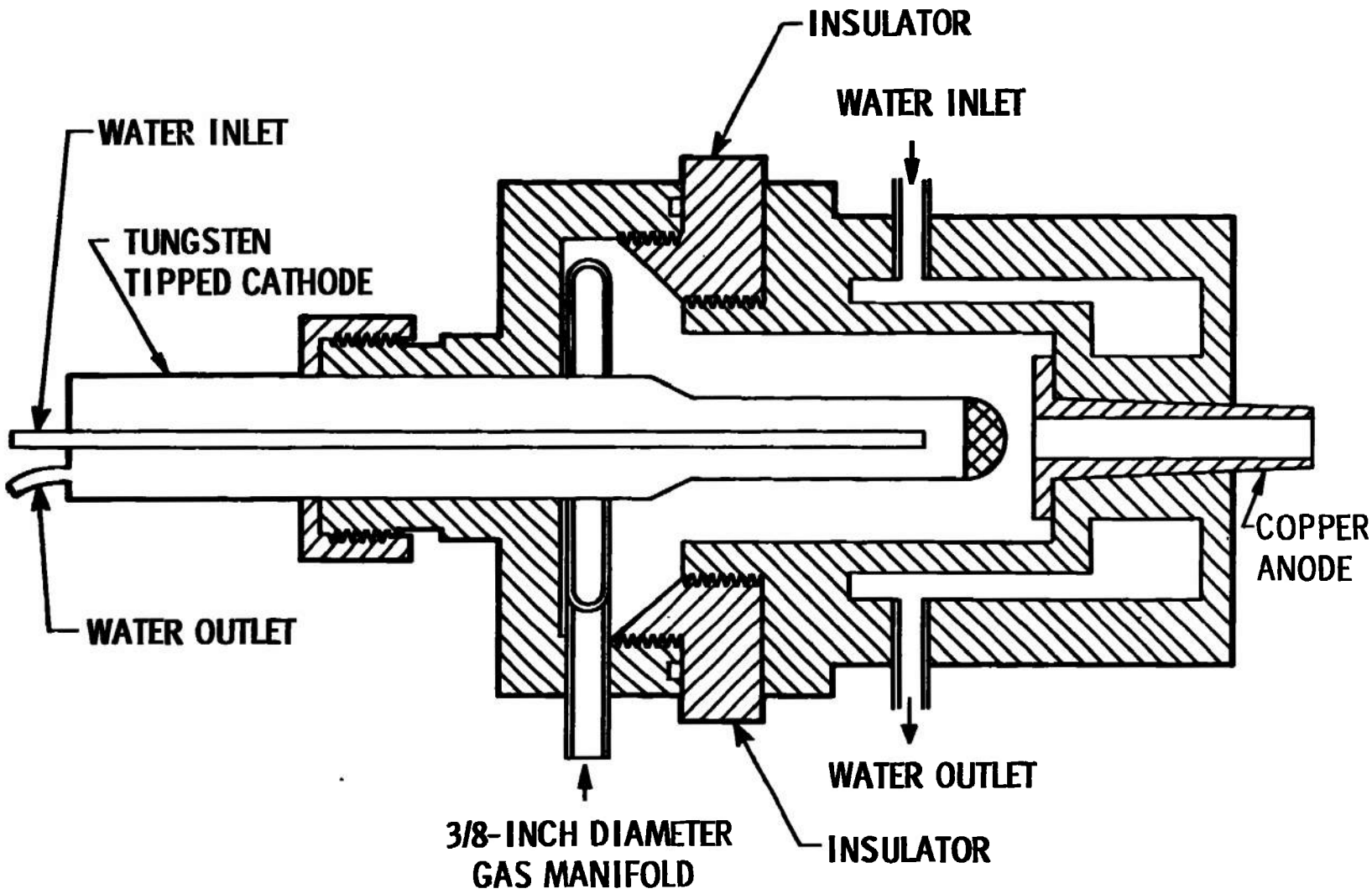
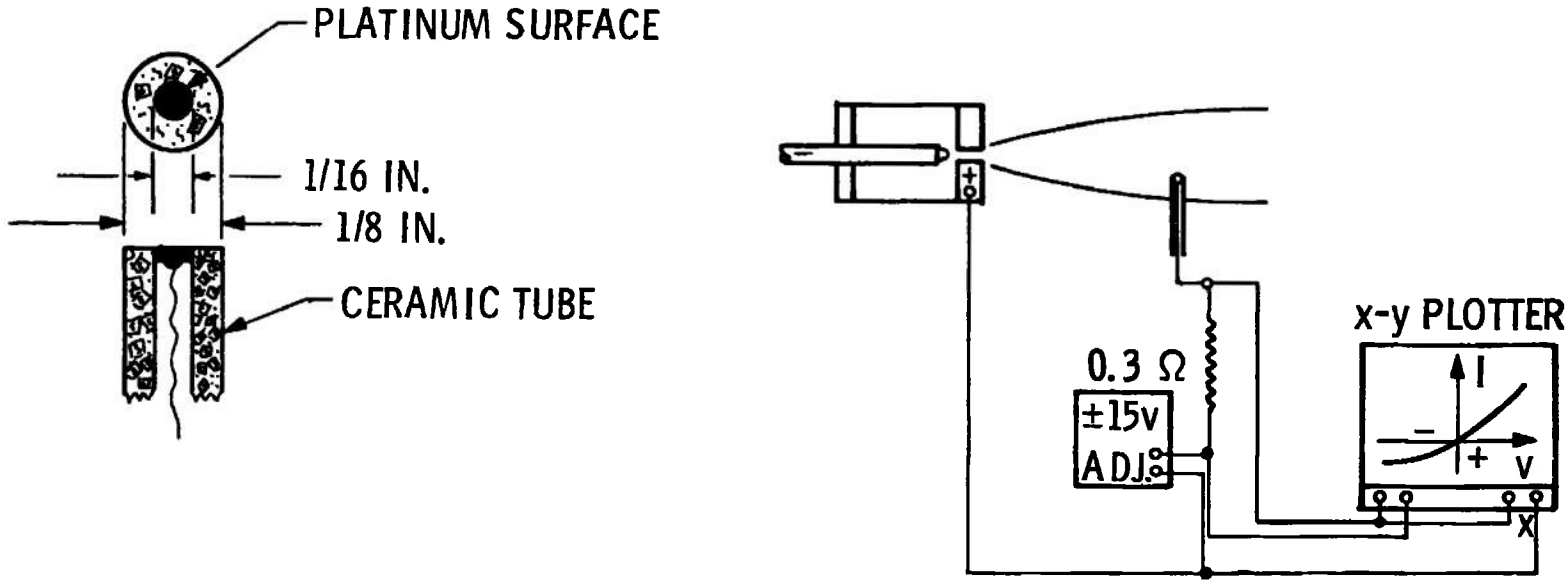


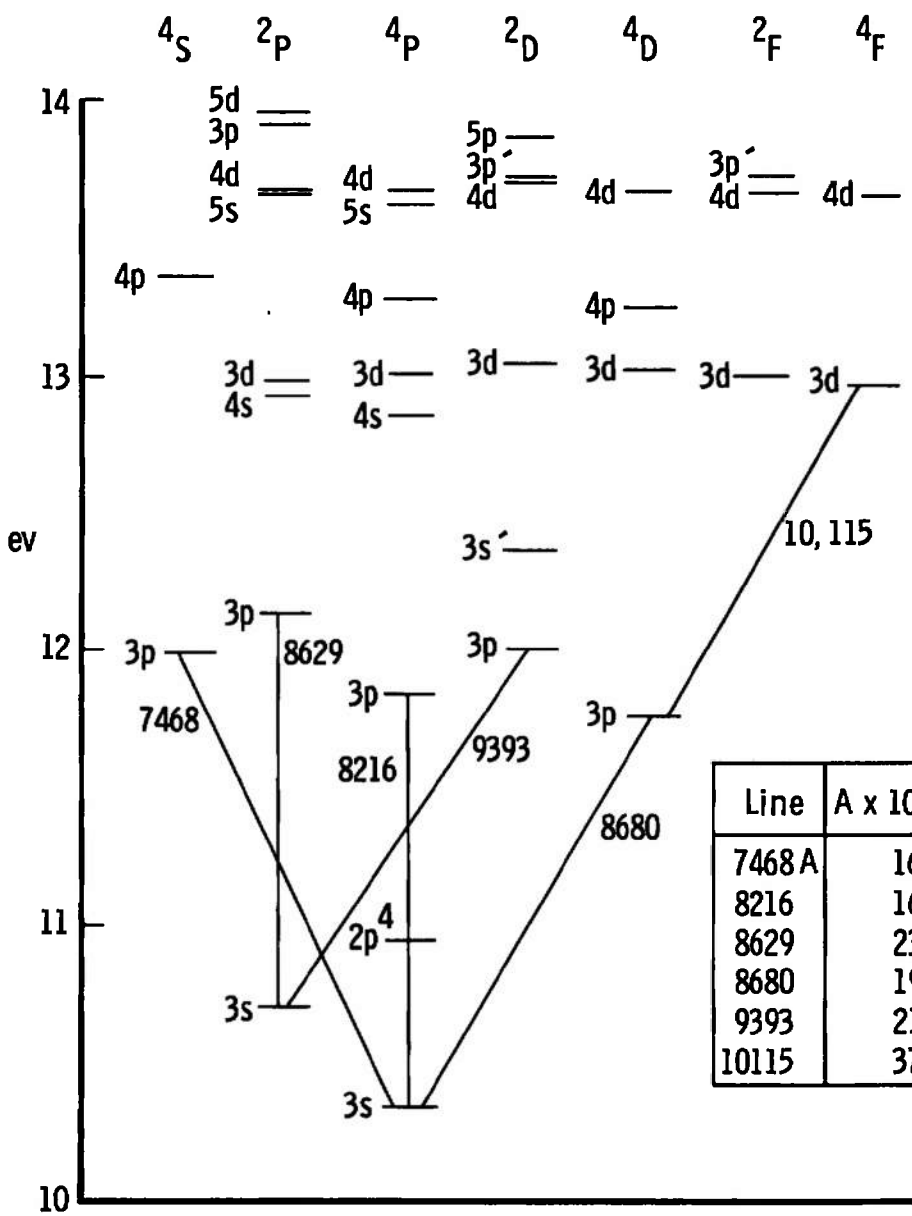
Fig. 2 Plasma Jet Cross Section



a. Probe Construction

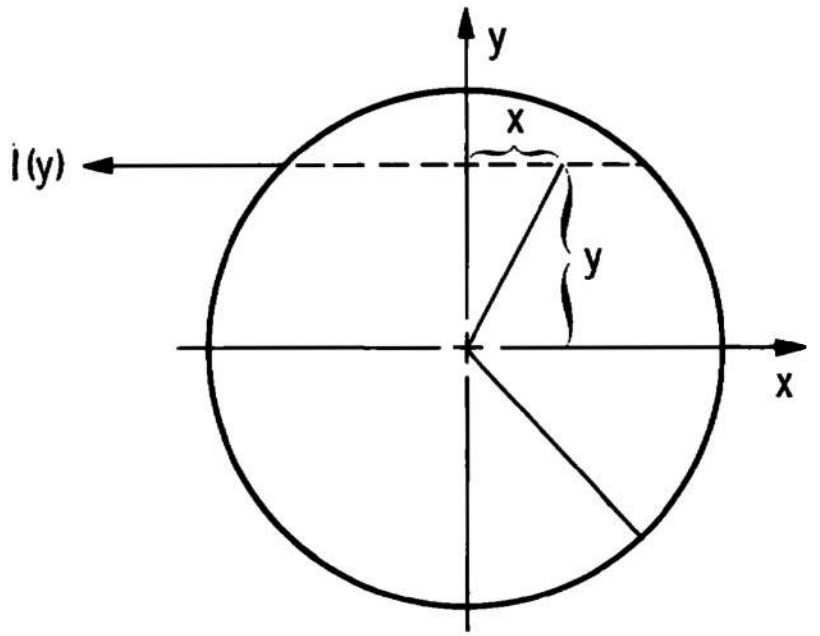
b. Probe Circuit

Fig. 3 Schematic of Langmuir Probe and Circuit Used for Plasma Electron Temperature Measurement

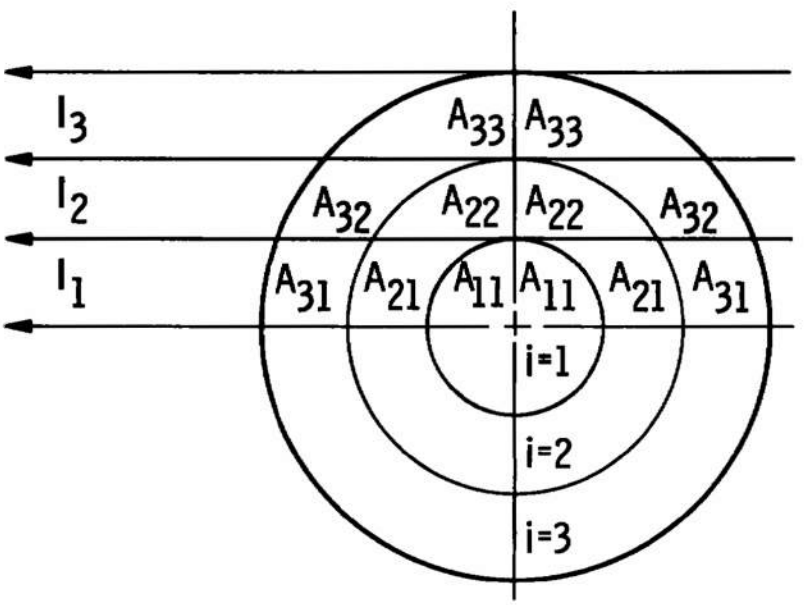


Line	A x 10^{-6} sec^{-1}	E_n (ev)
7468 A	16.1	11.997
8216	16.0	11.846
8629	23.8	12.128
8680	19.1	11.765
9393	21.8	12.011
10115	37.4	12.991

Fig. 4 Energy Level Diagram of the Nitrogen Atom



a. Integrated Intensity



b. Summed Intensity

Fig. 5 Schematic View of a Cylindrical Plasma Column

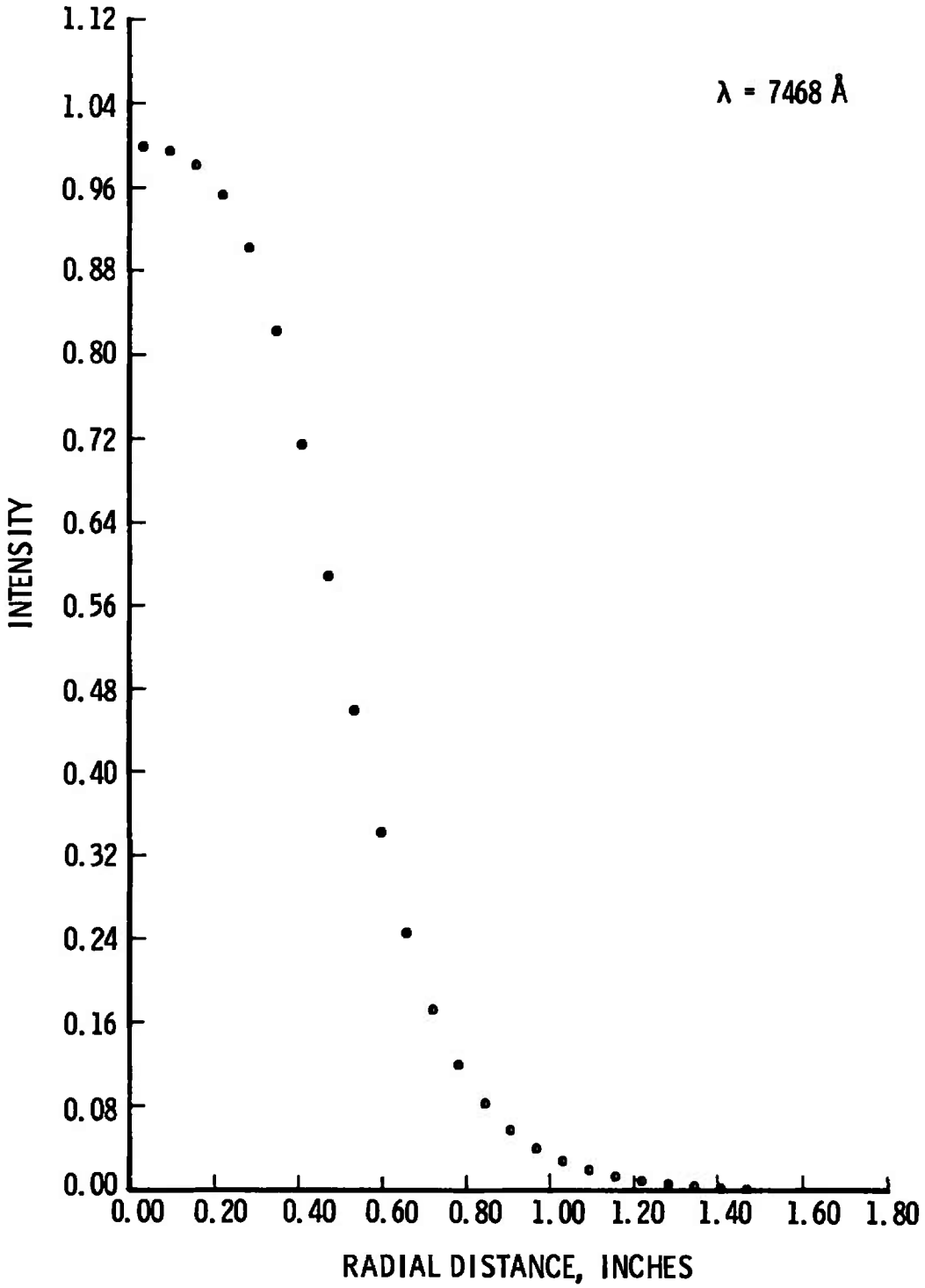


Fig. 6 Intensity Profile for the 7468-Å Line

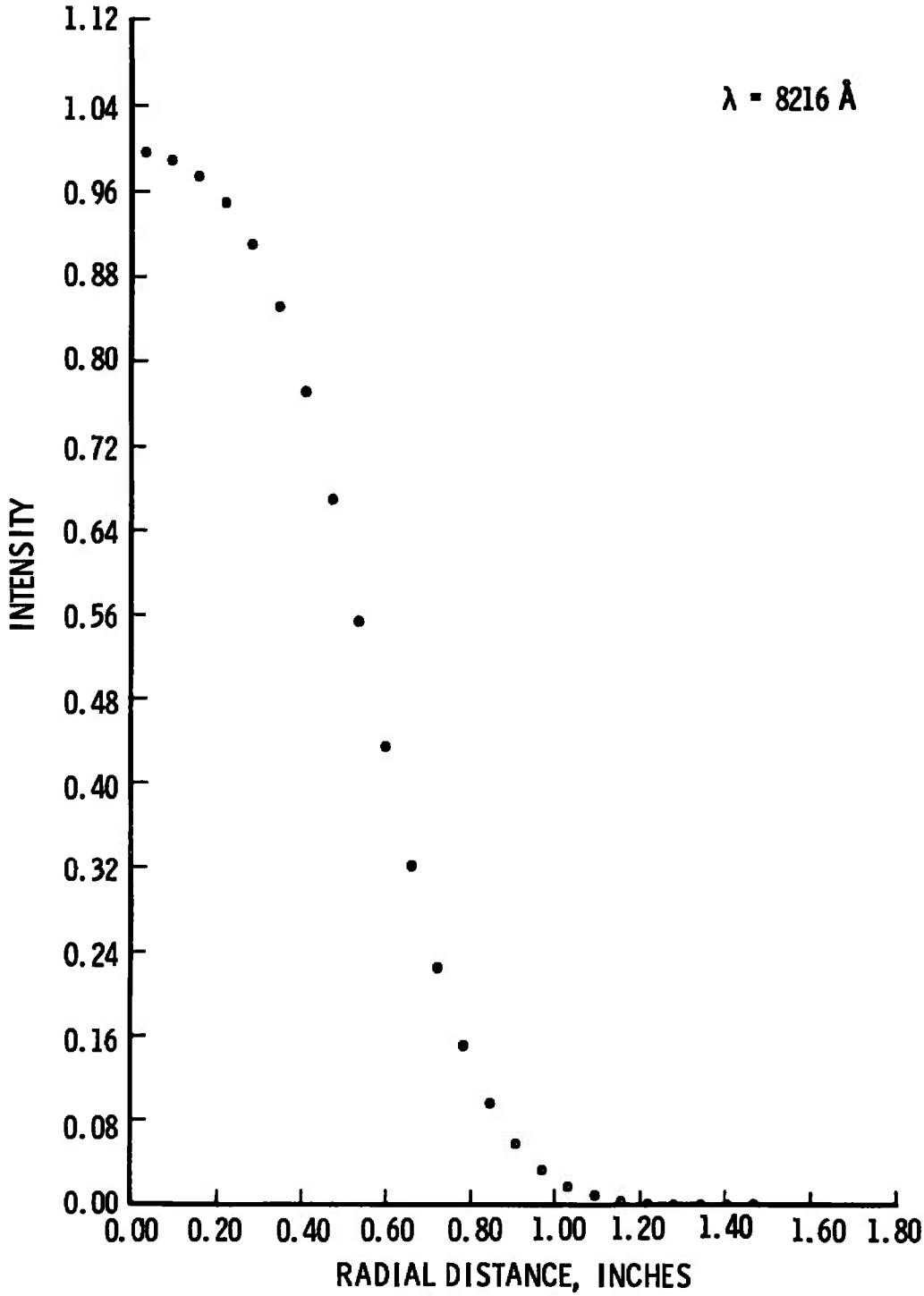


Fig. 7 Intensity Profile for the 8216-Å Line

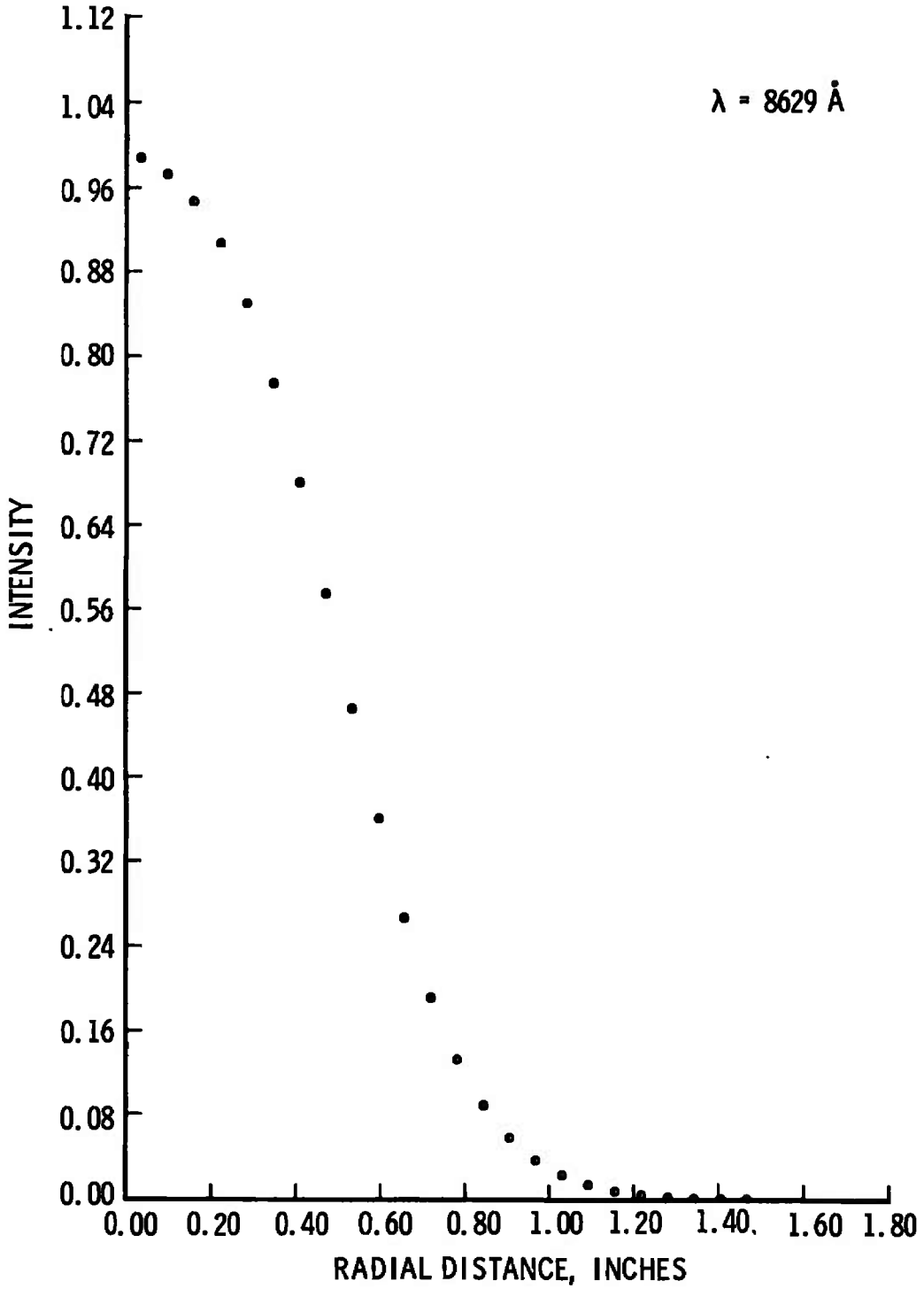


Fig. 8 Intensity Profile for the 8629-Å Line

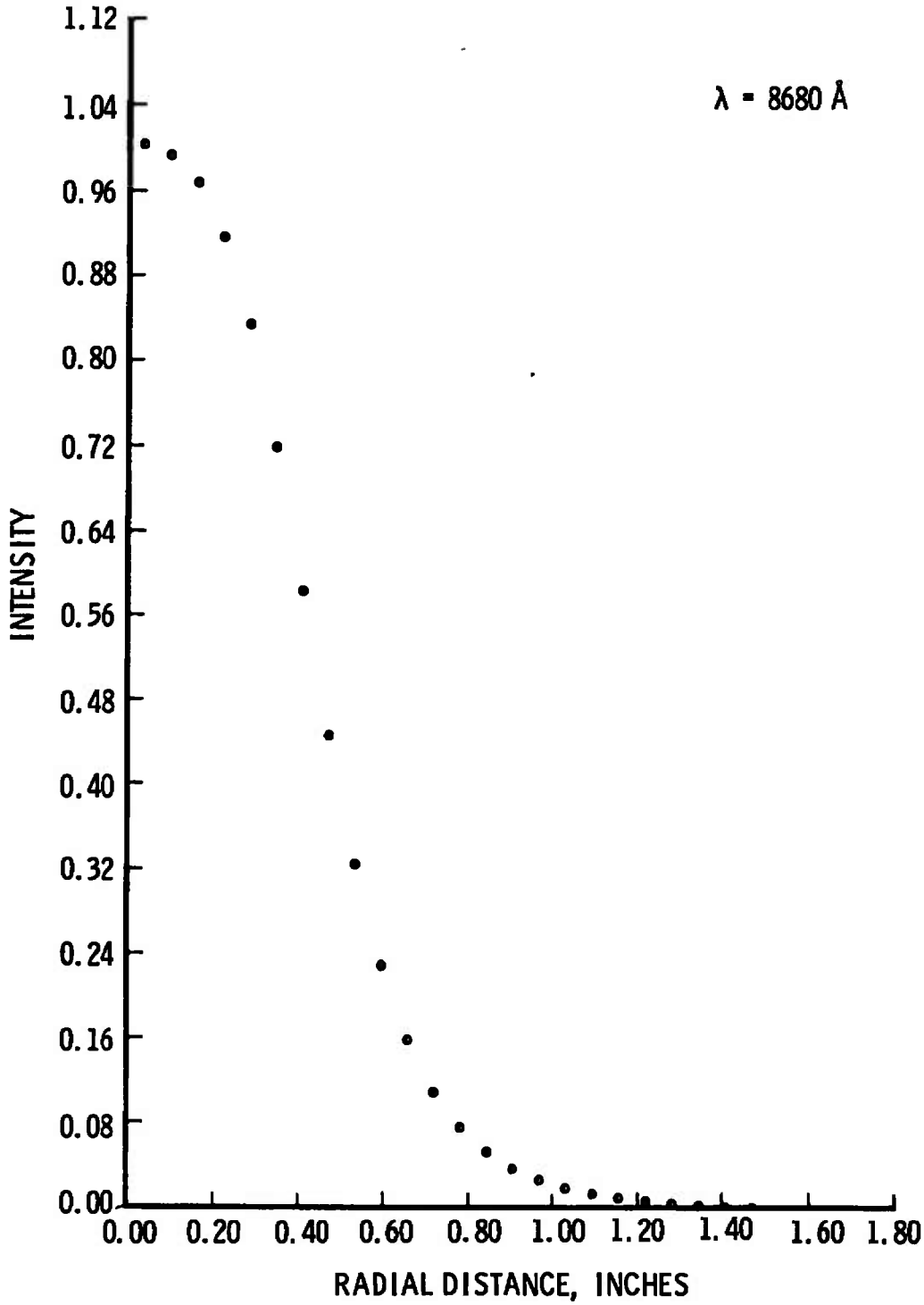


Fig. 9 Intensity Profile for the 8680-Å Line

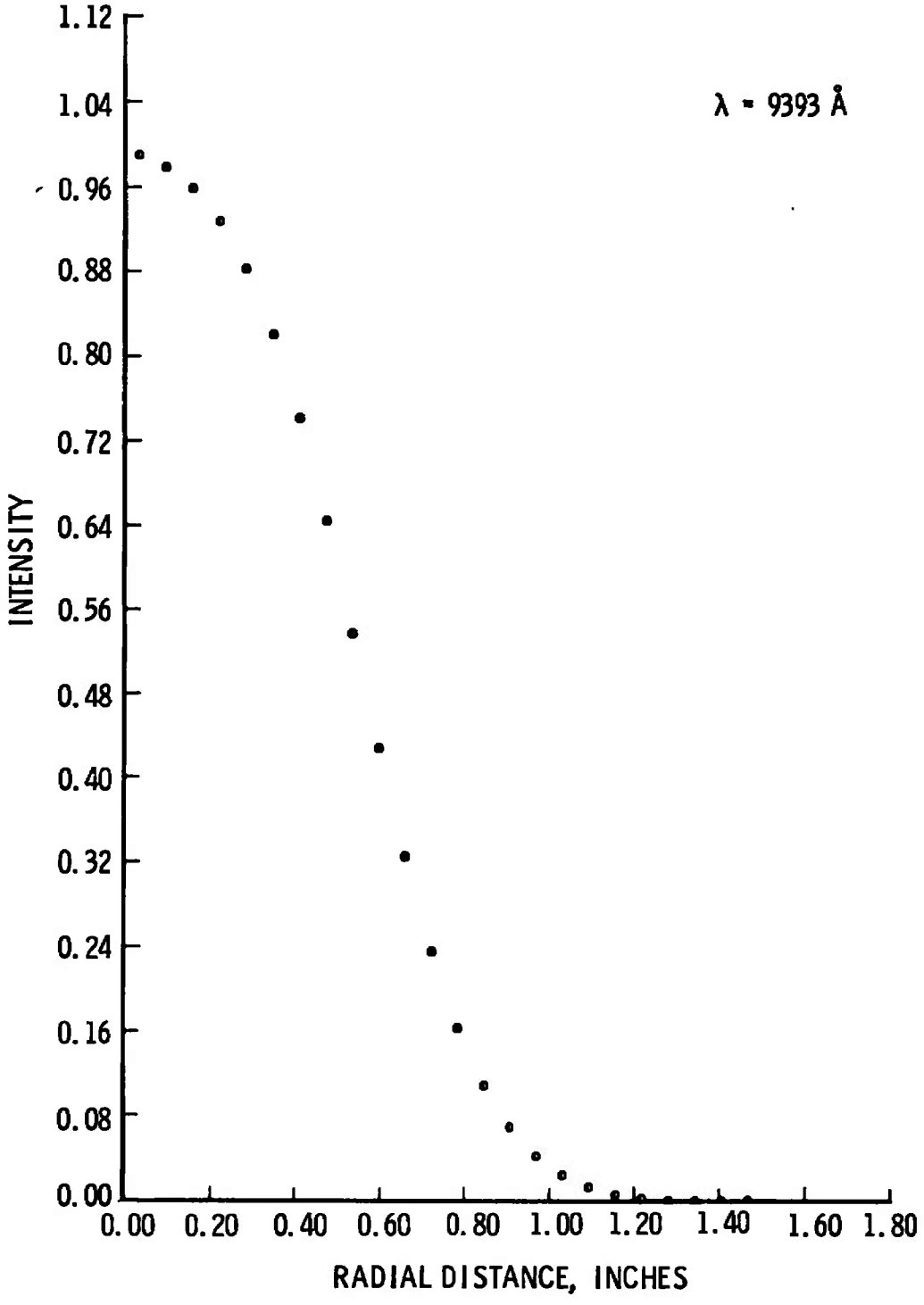


Fig. 10 Intensity Profile for the 9393-Å Line

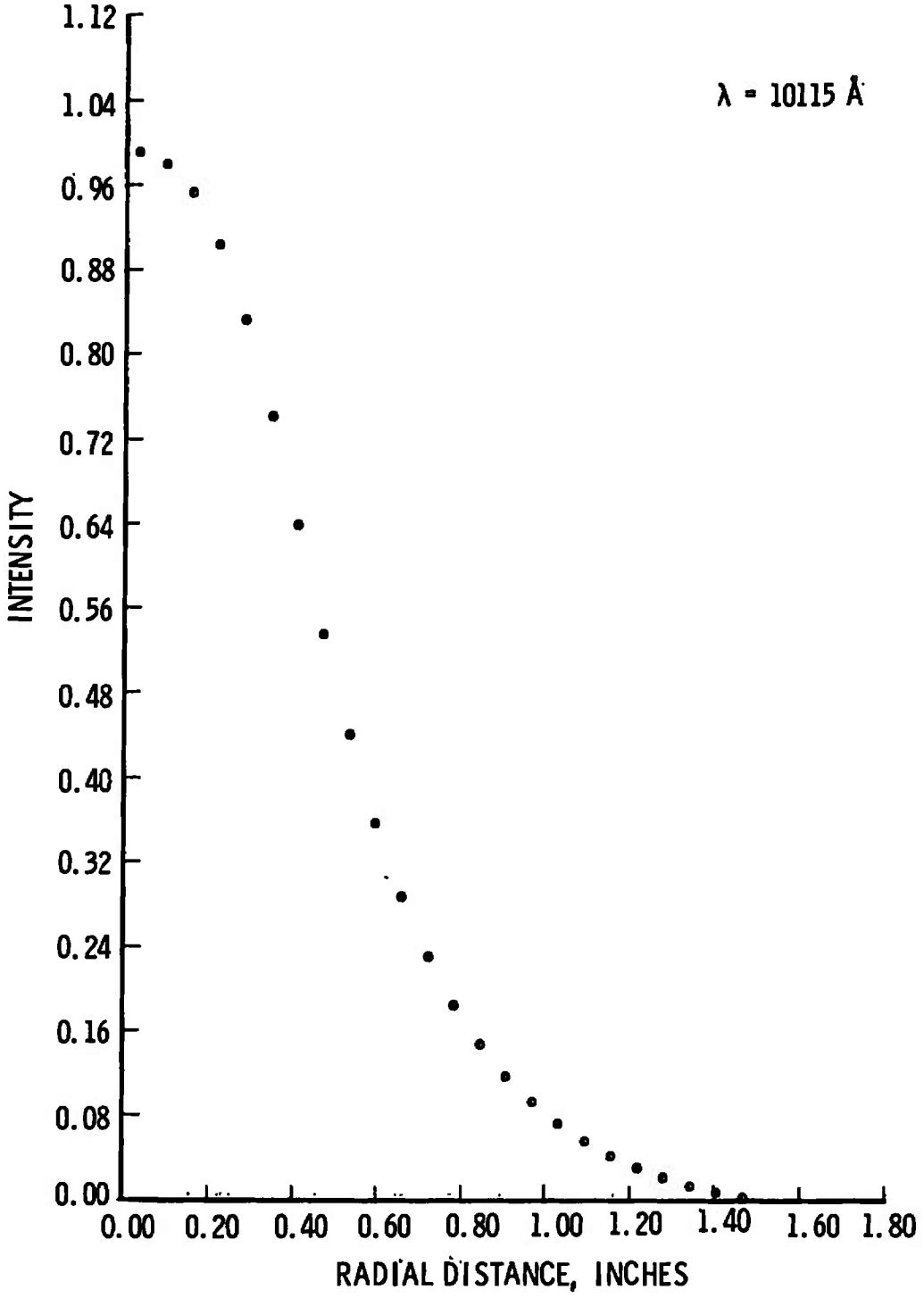


Fig. 11 Intensity Profile for the 10,115-Å Line

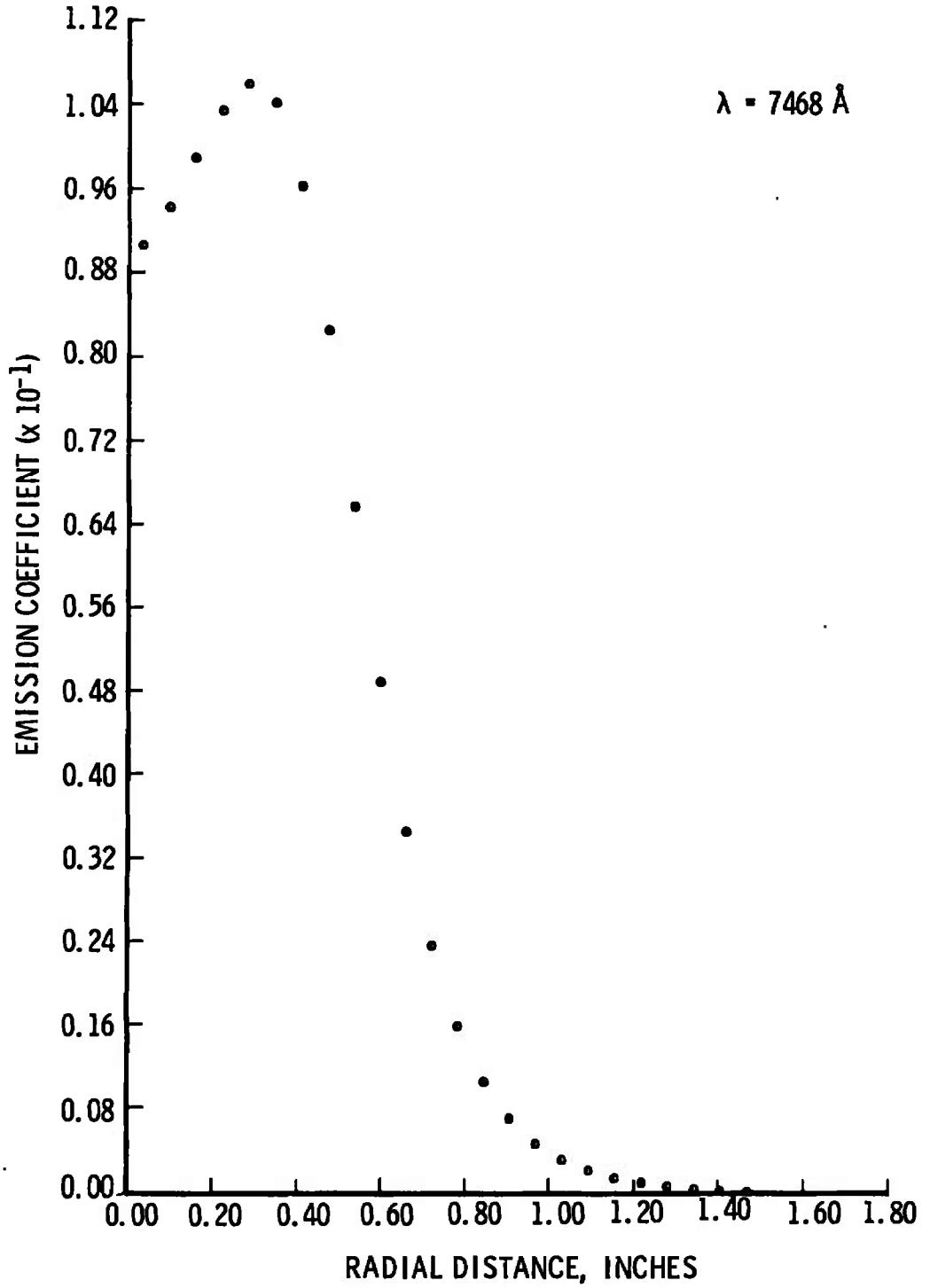


Fig. 12 Emission Coefficient Profile for the 7468-Å Line

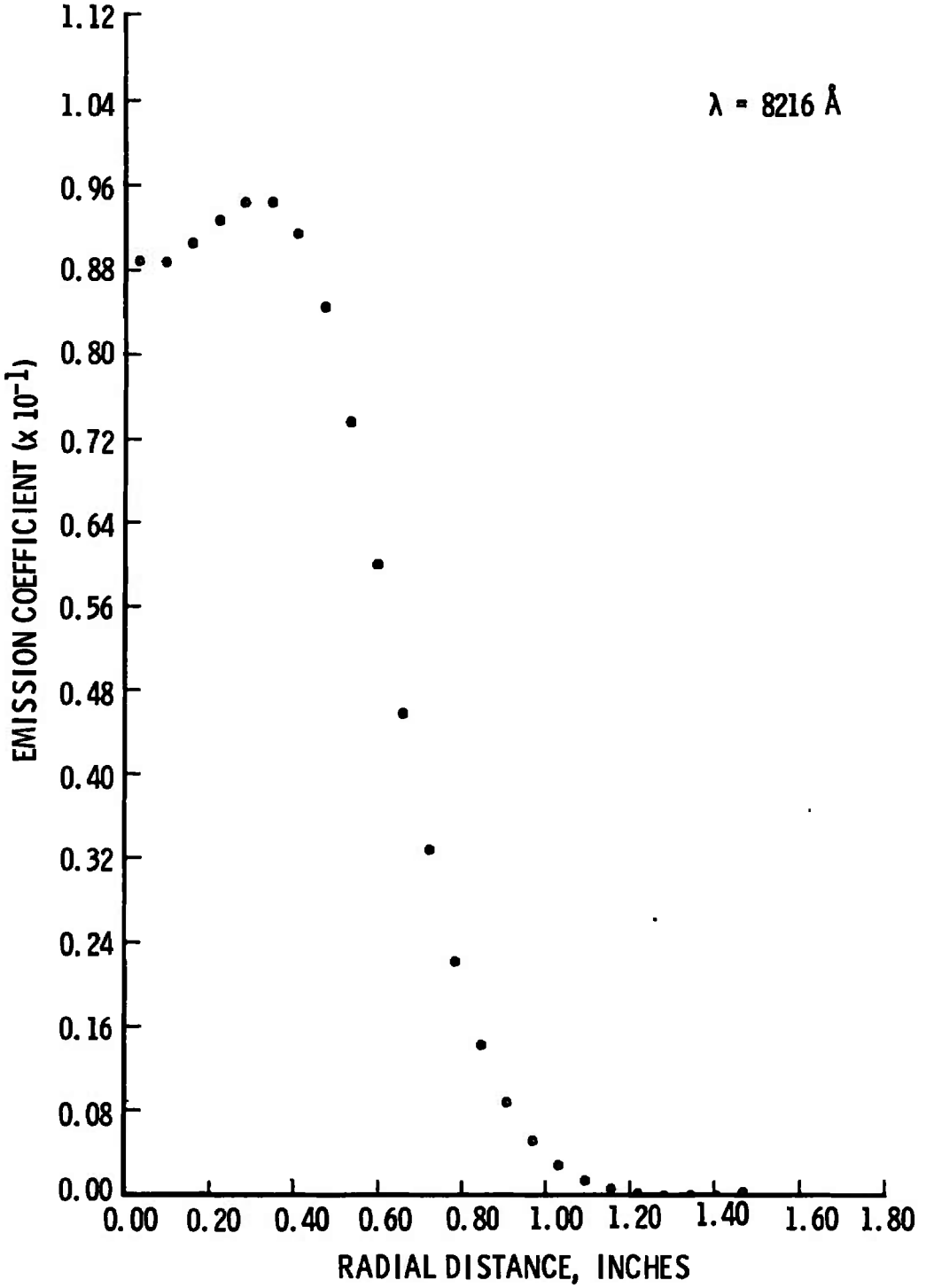


Fig. 13 Emission Coefficient Profile for the 8216-Å Line

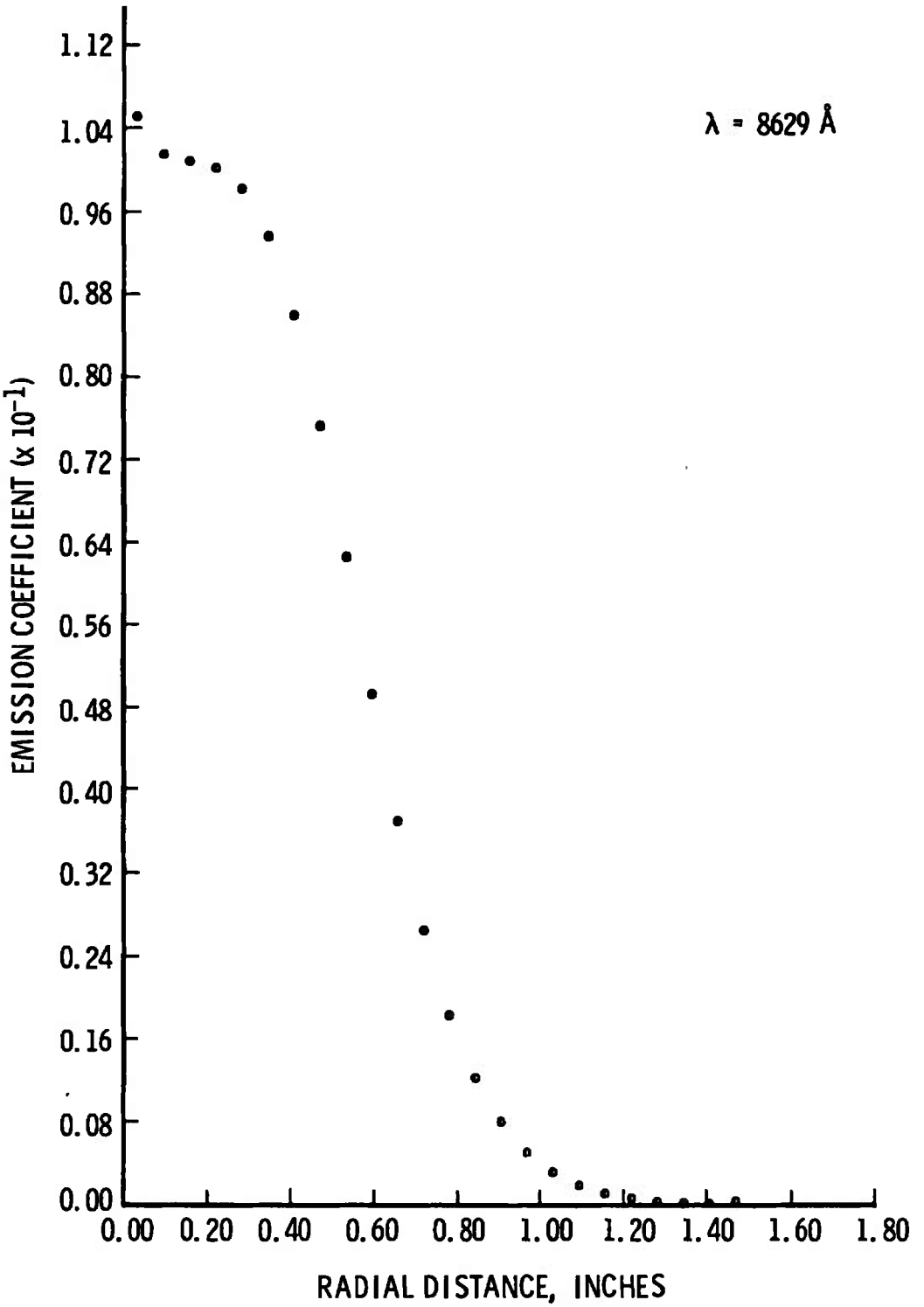


Fig. 14 Emission Coefficient Profile for the 8629-Å Line

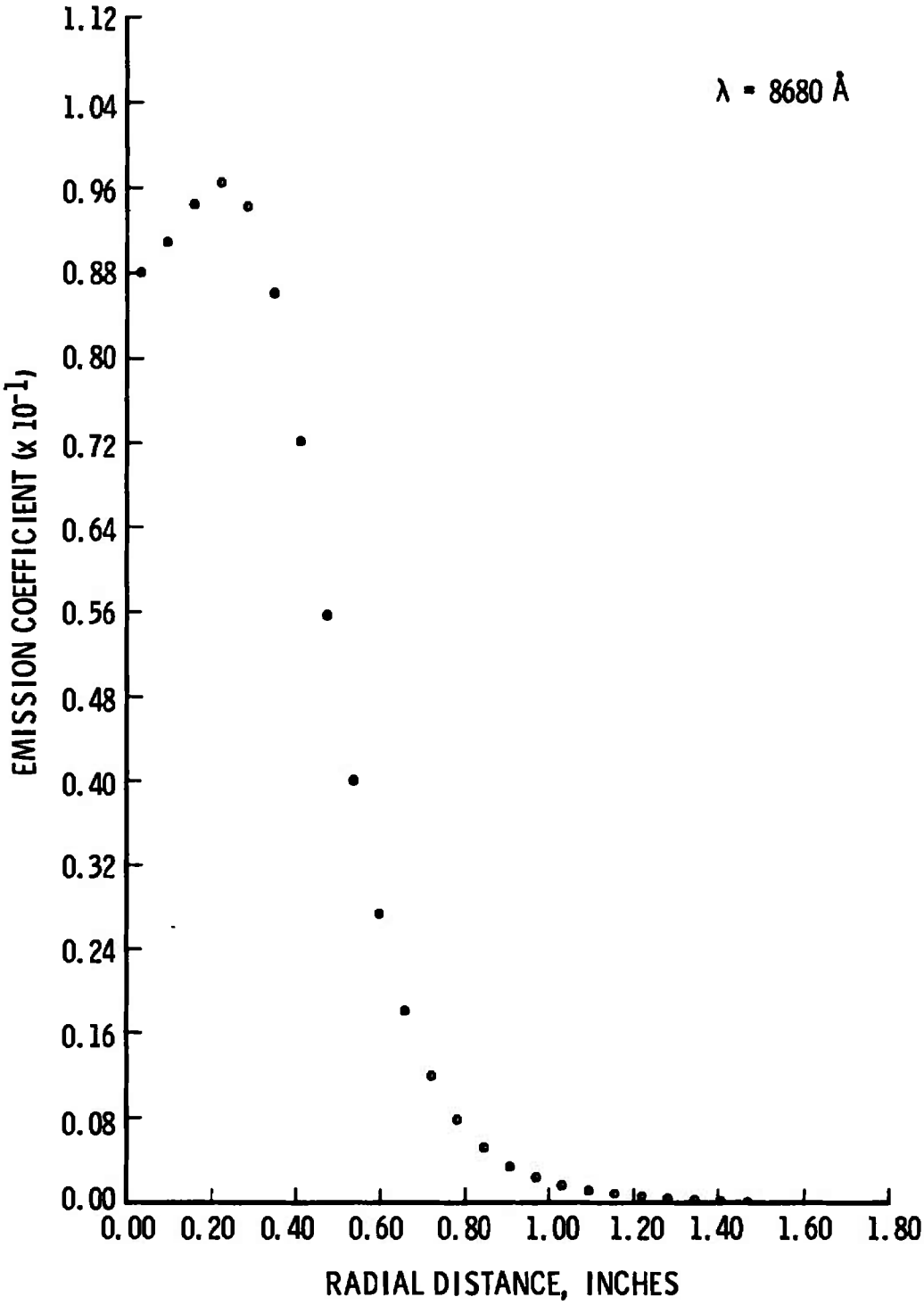


Fig. 15 Emission Coefficient Profile for the 8680-Å Line

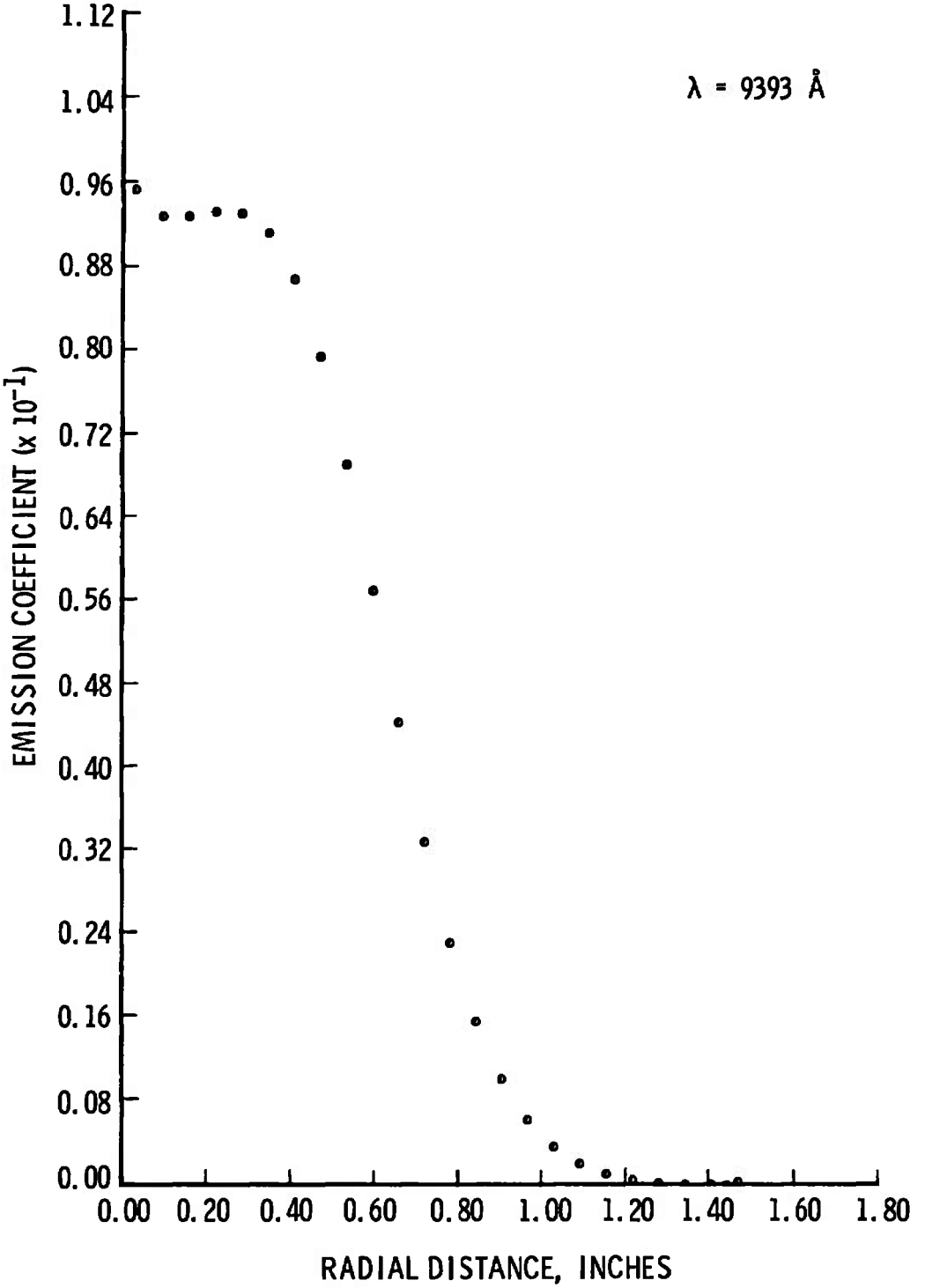


Fig. 16 Emission Coefficient Profile for the 9393-Å Line

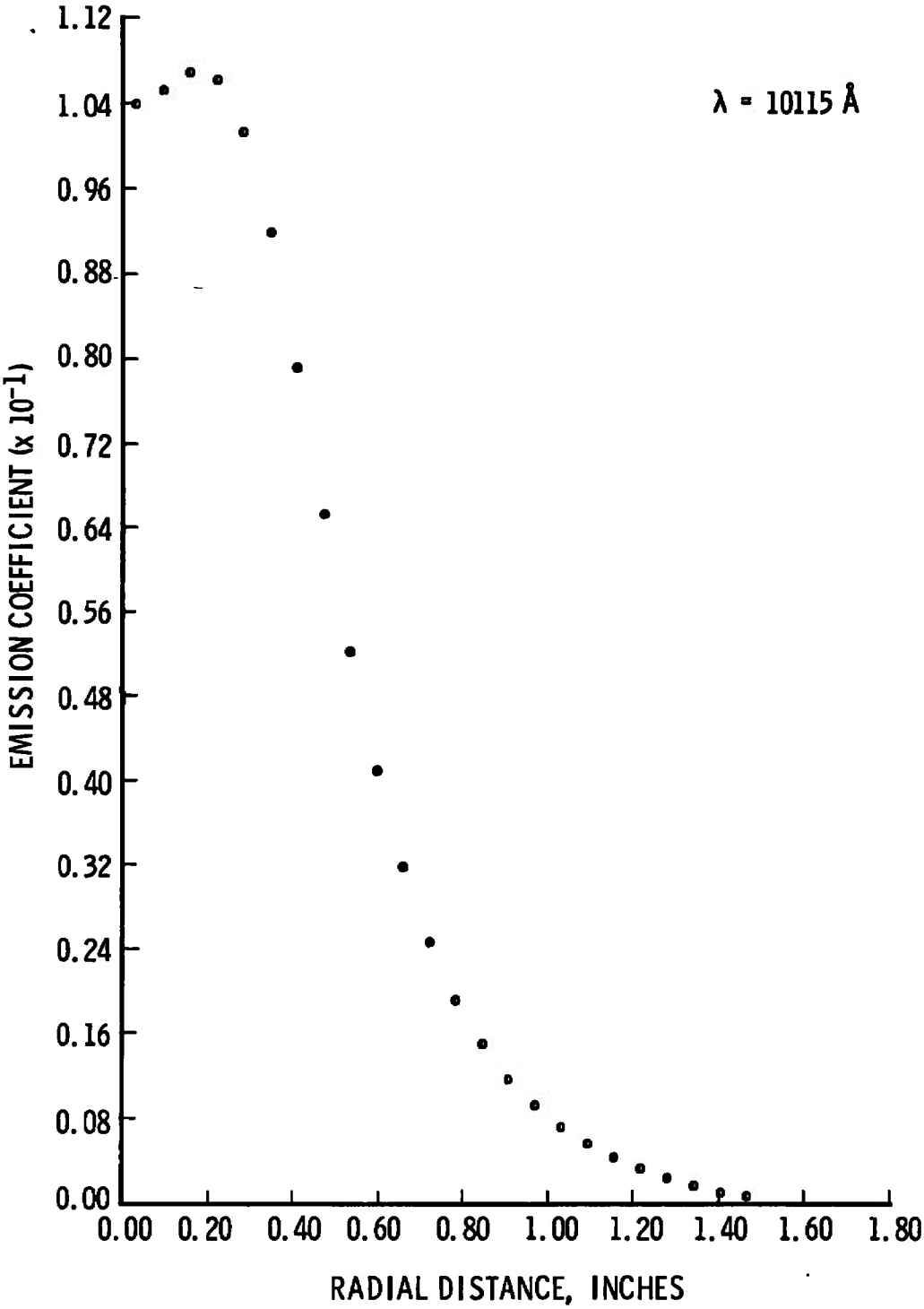


Fig. 17 Emission Coefficient Profile for the 10,115-Å Line

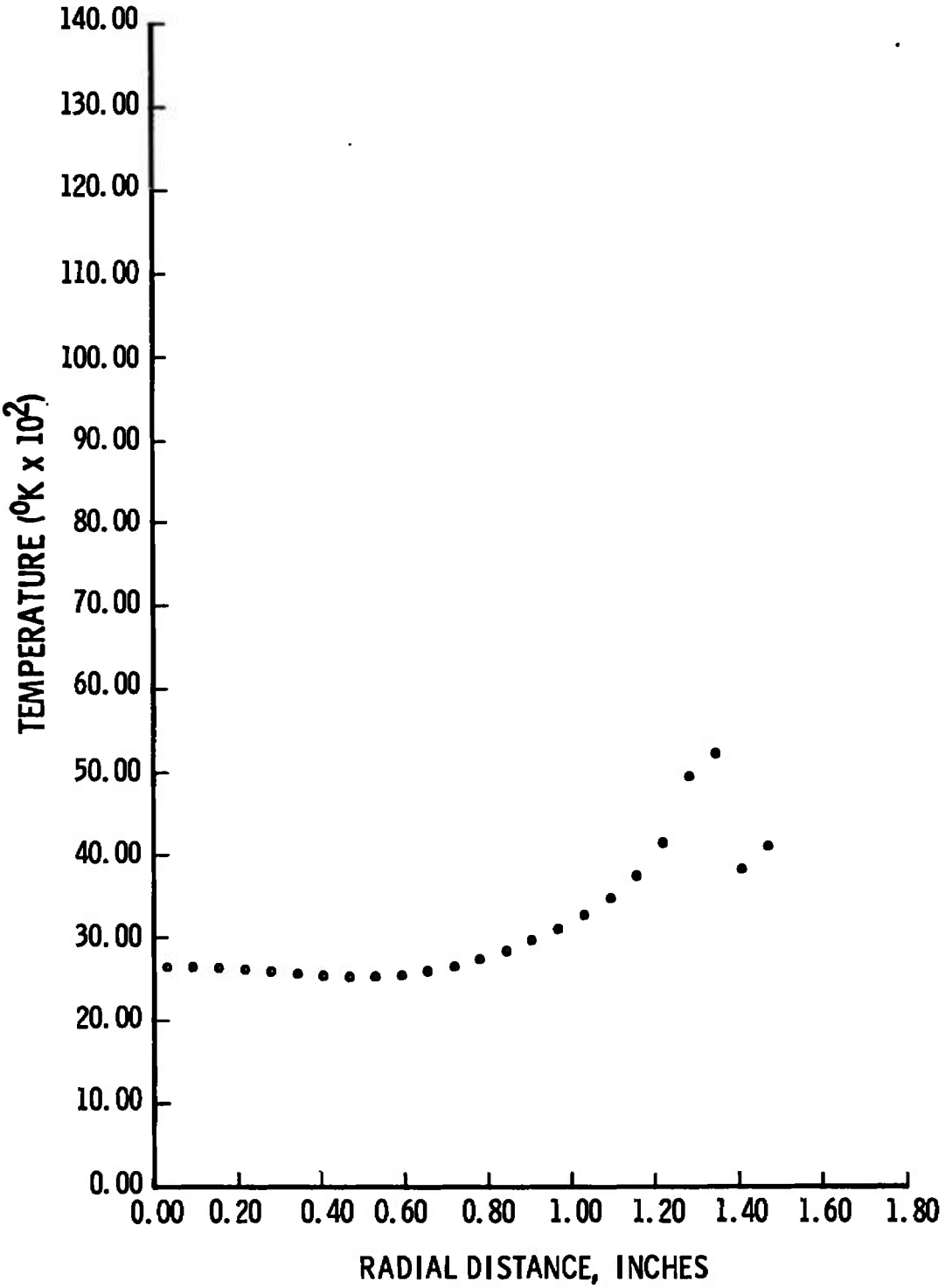


Fig. 18 Radially Inverted Excited Temperature Profile

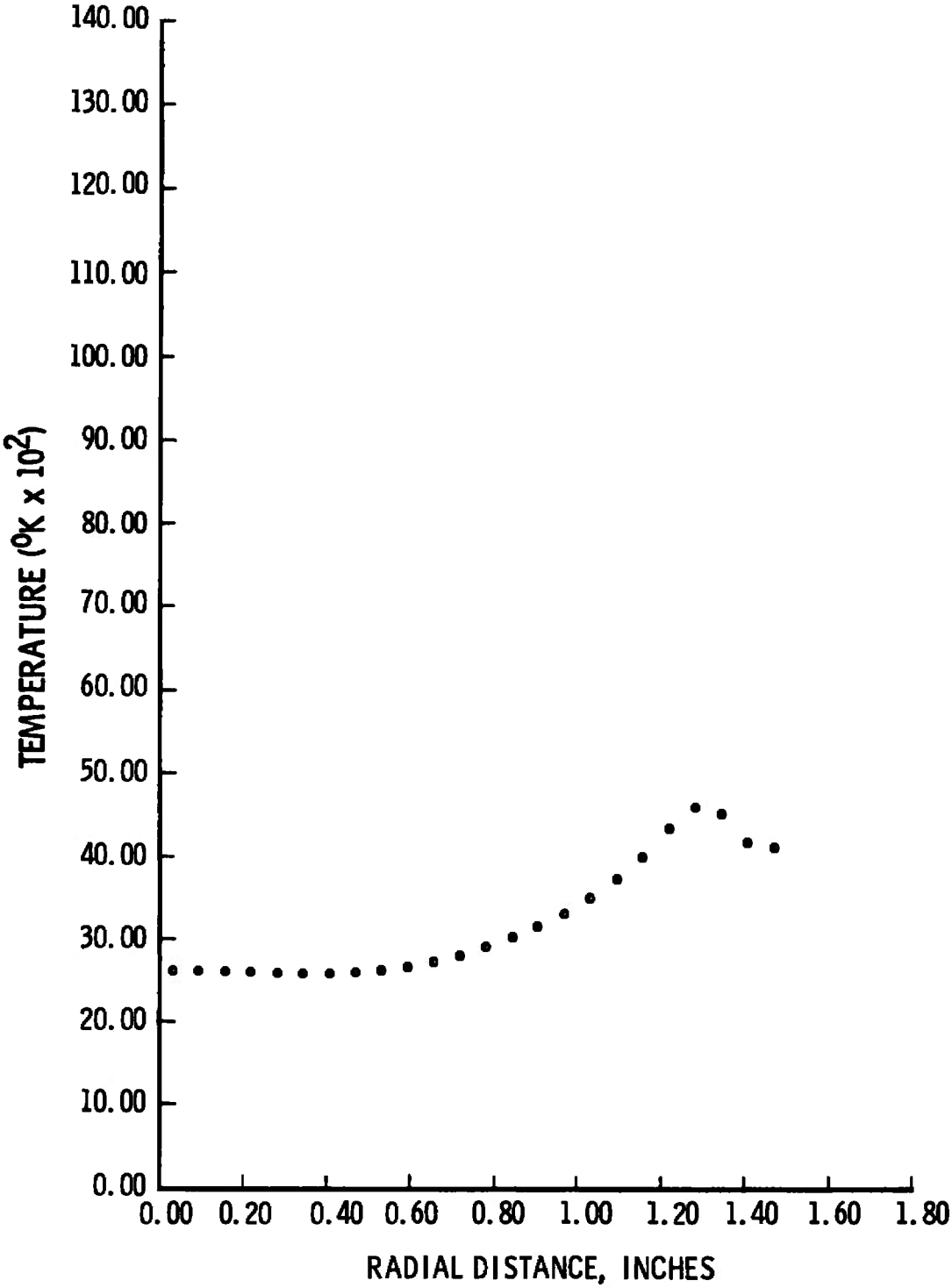


Fig. 19 Weighted Excitation Temperature Profile

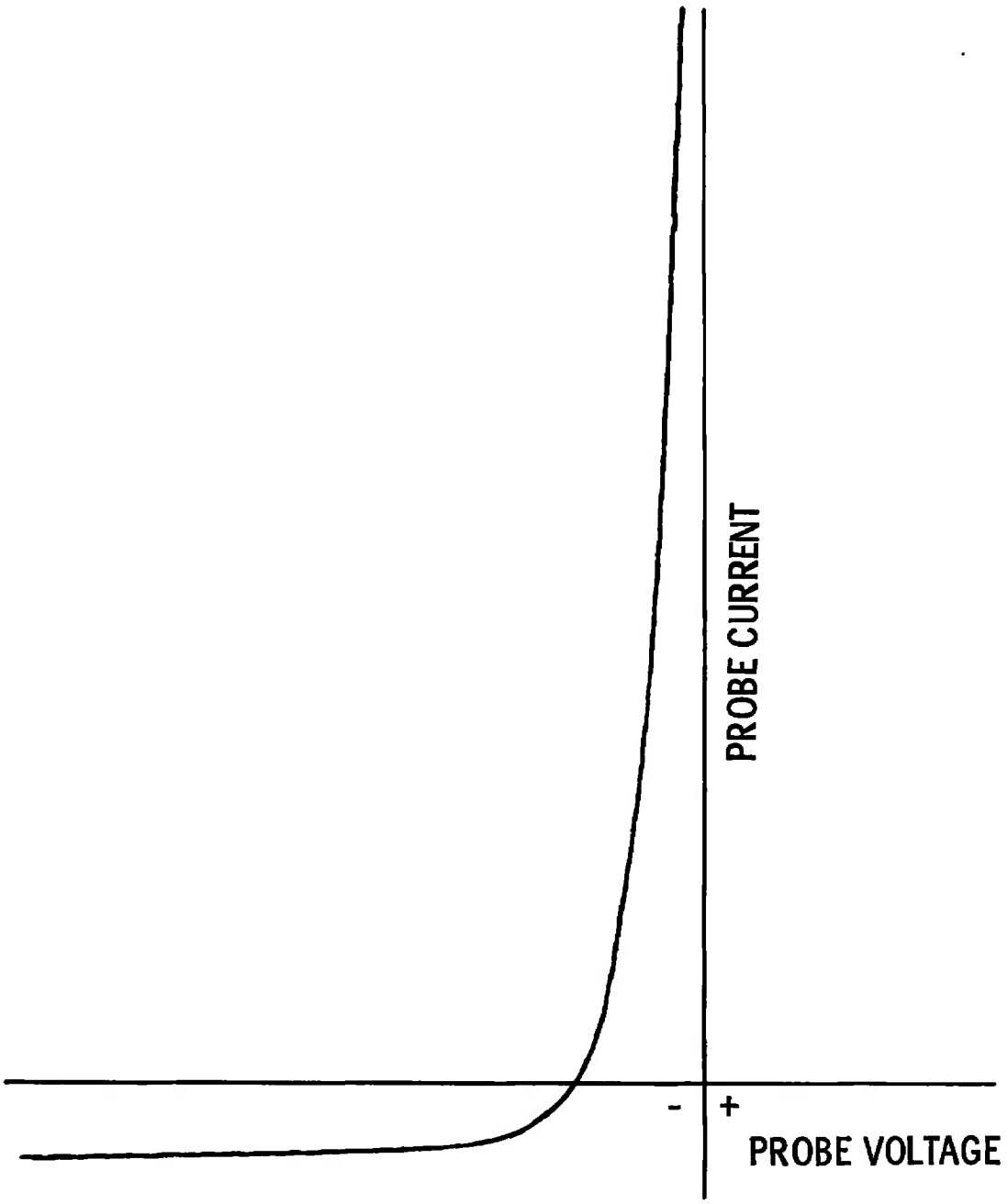


Fig. 20 Typical Langmuir Probe Data

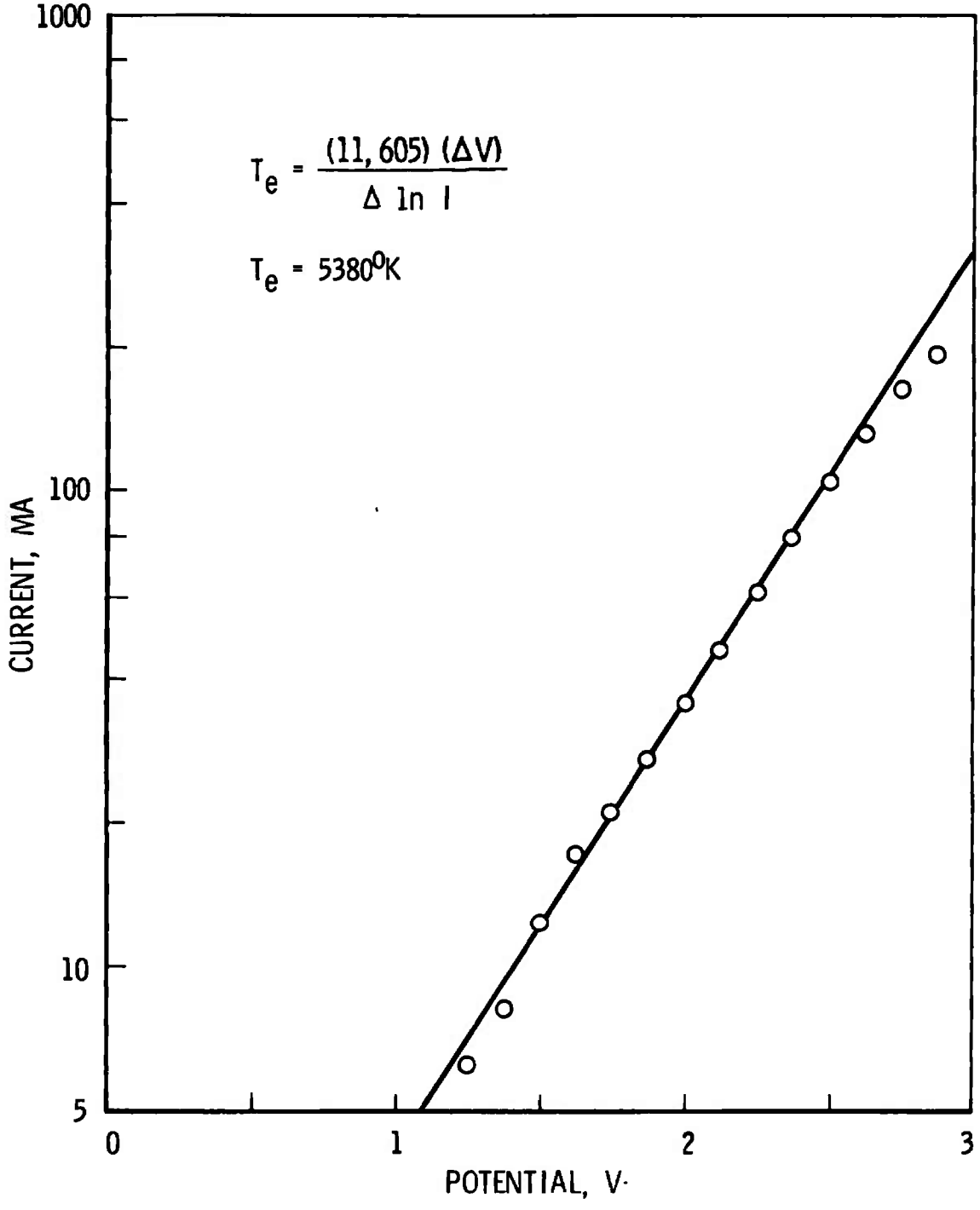


Fig. 21 Log Plot for Electron Temperature Measurement

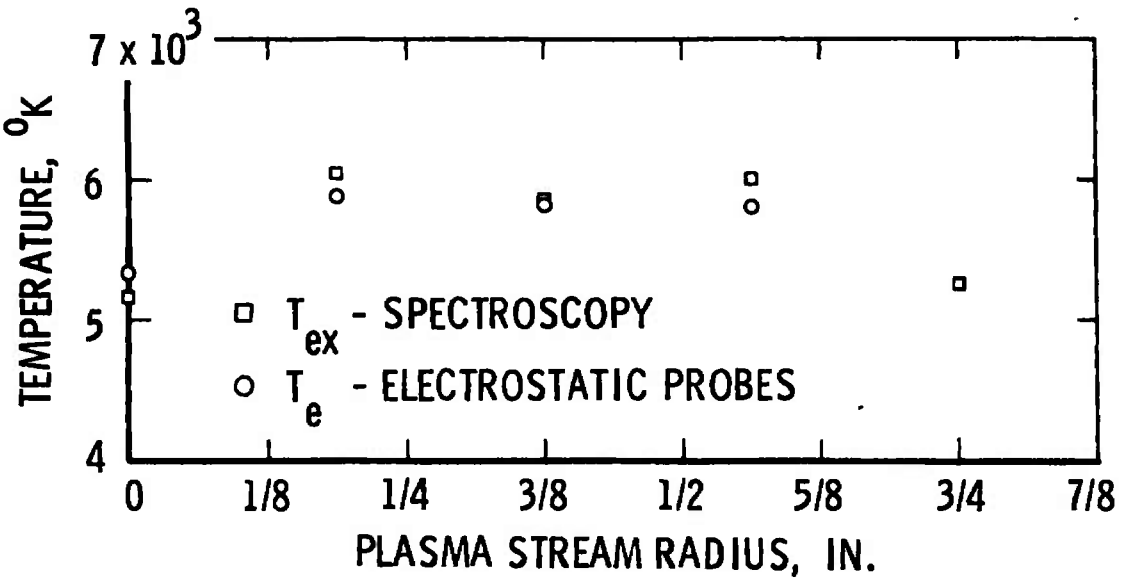


Fig. 22 Results of Temperature Measurement on o Low-Density Argon Plasmo Stream by Spectroscopy and by Electrostotic Probes

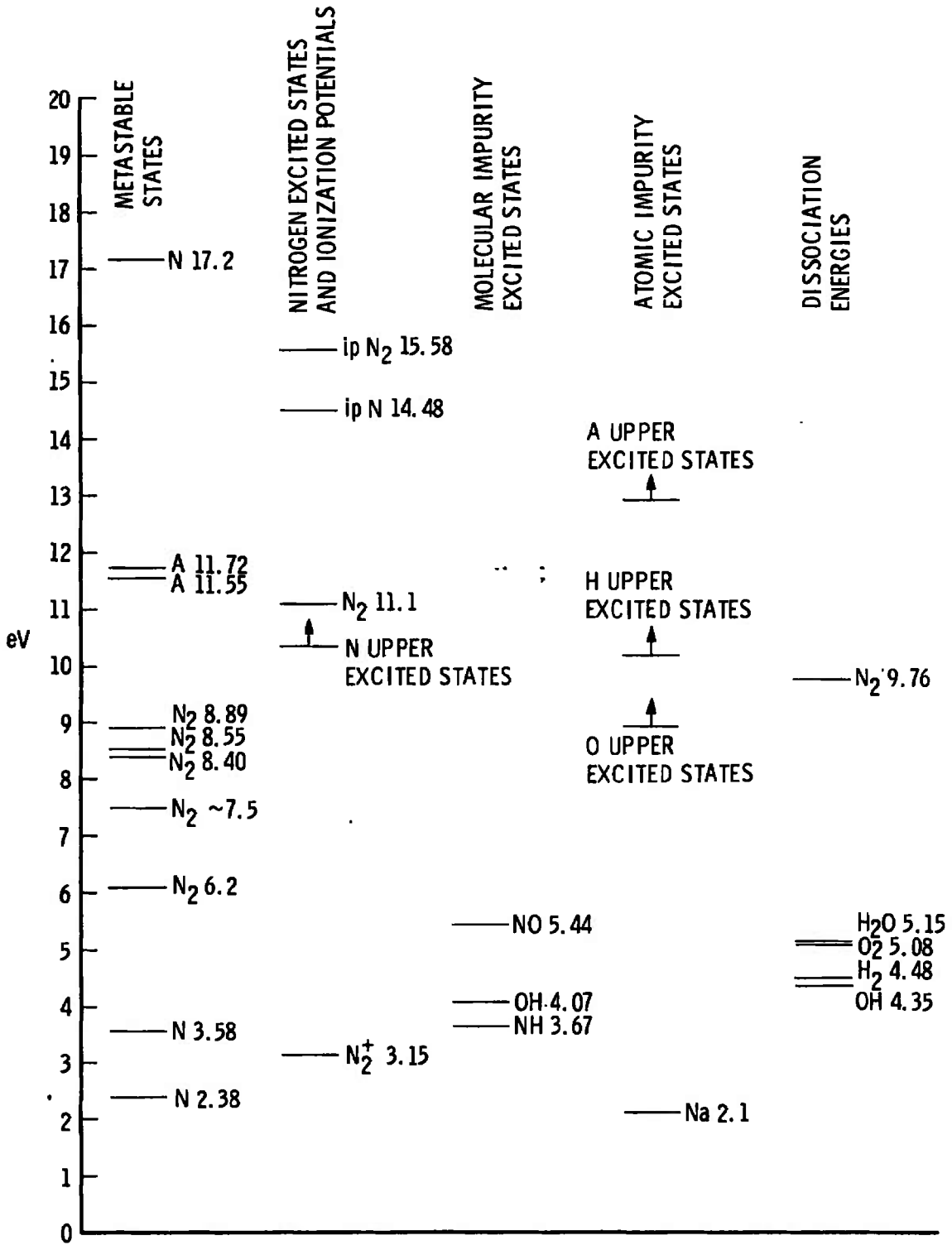


Fig. 23 Comparative Energy Level Diagram for all Species Observed in Nitrogen-Argon Plasmas

TABLE I
RESULTS OF SPECTROSCOPIC AND LANGMUIR PROBE TEMPERATURE MEASUREMENTS

Radial Position, In.	Spectral Line Method, °K	Langmuir Probe Method, °K
Centerline	2677	4973
1/4	2652	4552
1/2	2561	4922
3/4	2690	4971
1	3141	5208

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13 ABSTRACT

The objective of this work was to measure the atomic line radiation of nitrogen in the spectral range from 7000 to 12,000 Å and to examine the population distribution of excited states to determine if a Boltzmann distribution existed and consequently whether an excitation temperature could be defined. Simultaneous measurements using Langmuir probes were made to determine electron temperatures. These measurements were applied to a low-density plasma produced in an arc-jet and expanded into a low-pressure chamber. A one-meter Czerny-Turner scanning spectrometer was used to record the atomic line spectra. Results indicate a difference in the spectroscopic temperature measurements and Langmuir probe measurements of approximately 2000°K. Reasons for this difference are discussed.

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